Could Bioenergy be used to Harvest the Greenhouse: An Economic Investigation of Bioenergy and Climate Change?

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Table of Contents

1 Introduction

Bioenergy interest has been greatly stimulated by the fuel price rises in the late 2000's. Bioenergy is seen as a way to protect against the rising fossil fuel prices and the political insecurity of importing petroleum from the Middle East. Furthermore, growing evidence suggests that combustion of fossil fuels is precipitating climate change (Intergovernmental Panel on Climate Change, 2007). Thus, at present three factors may influence the prospects for bioenergy: 1) increases in crude oil prices, 2) concerns for national energy security matters and 3) concerns for climate change and global warming.

All three of these factors have an impact on the production and consumption of liquid biofuels such as ethanol and biodiesel. However, increasing petroleum prices do not matter as much for biopower – biomass used in electricity production. This is because electricity generation uses little petroleum and instead relies on coal and natural gas which are abundant in the US (Table 1). Also because of the possibility of substitution among various fuel sources in electricity production, any increase in oil and gas prices will urge power producers to switch to other fuel sources especially coal (Sweeney, 1984). However, concern for climate change and the introduction of a cap and trade permit system for greenhouse gases (GHG) could stimulate interests in biopower.

EPA data show that electric power generation is the biggest source of US greenhouse gas emissions, followed by the transportation sector (Figure 1). Burning coal produces more carbon dioxide (CO_2) than any other method of generating energy, with coal used to generate more than half of US electricity (Table 1). Agriculture may offer a way to reduce net GHG emissions and thereby help mitigate the risks of climate change (McCarl and Schneider, 2000). Agricultural products, crop residues and wastes may be used as substitutes for fossil fuel products to fuel electric power plants or as inputs into processes making liquid biofuels.

Because plant growth absorbs CO_2 while combustion releases it, using agricultural products to generate energy generally involves recycling of CO_2. This suggests that bioenergy producers or consumers would not need to buy GHG or carbon emission permits (assuming a GHG trading market exists) when generating biopower or consuming liquid biofuels. As long as bioenergy does not require acquisition of potentially costly emission permits, carbon permit prices could raise the market value of agricultural products. As a result, agricultural producers can gain income by supplying biofeedstocks, while energy producers can effectively reduce GHG emissions and carbon permit expenditures.

Before embracing bioenergy as a GHG mitigation mechanism, one must fully consider the GHGs emitted when growing, harvesting, and hauling feedstocks, and then converting them into bioenergy. In addition, one must also consider the market effects and possible offsetting effects of production induced elsewhere. Two issues arise from this: 1) What are the GHG offsets obtained when using a particular form of bioenergy and what does this imply for comparative economics of feedstocks? 2) When bioenergy production reduces traditional commodity production does the indirect market effect reduce net GHG effects?

In this chapter, we examined the technology and economics of bioenergy. First, an agricultural model, FASOMGHG, is introduced. The agricultural model allows the researchers to simulate the agricultural markets, because bioenergy competes for feedstocks with the agricultural industries. Second, an overview of bioenergy possibilities is examined and how the bioenergy industry relates to the agricultural markets. Finally, the agricultural model is used to predict the future production levels of bioenergy given various fossil fuel and GHG prices, and whether bioenergy could mitigate climate change.

2 Modeling Background

The Forest and Agricultural Sector Optimization Model-Greenhouse Gas version, herein referred to as FASOMGHG, is used to predict production levels over time for biofuels and biopower. FASOMGHG is a mathematical programming model that contains markets for bioenergy, biofeedstocks and byproducts plus conventional agricultural and forestry commodities, accounting for market interactions, hauling and processing costs, and GHG emissions. Each activity may release or sequester GHG. The U.S. agriculture is divided into 63 production regions. Each region has unique climate, soil fertility, and water resources. Producers can produce the primary crops and livestock shown in Table 2. FASOMGHG also includes constraints on land usage and production activities for each region. Producers take the primary crops and livestock and can produce the secondary products shown in Table 3. Processing activities are modeled in 11 aggregate market regions for the United States. Furthermore, FASOMGHG allows primary and secondary products to be imported or exported. Currently, the bioenergy commodities are not internationally traded (Lee 2002, Adams et al. 2005).

2.1 Lifecycle Accounting

GHGs are emitted during the entire production lifecycle arising from fossil fuels and other inputs used to produce biofeedstocks and transform then into bioenergy. Generally, GHG emissions are generated when production inputs are manufactured, and when the bioenergy feedstock is grown, harvested, hauled and processed into fuel or electricity. FASOMGHG contains net GHG emissions and sequestration for a large variety of agricultural activities.

The net GHG contribution of bioenergy production depends on the GHG emissions encountered during the biofeedstock to fuel to byproduct lifecycle. This contribution varies by feedstock, bioenergy product type, and region. Employing data from regions which have high potential for feedstock production, Table 4 shows estimates across a number of possibilities for use of crop or cellulosic ethanol in place of gasoline, biodiesel in place of diesel and biopower produced with the biofeedstock used to both cofire 5% and fire 100%.

When corn-based ethanol is used, the percentage reduction in net GHG emissions is about 31% relative to the use of gasoline as shown in Table 4. The table also shows that the emission-offset rates are higher for electricity mainly because the feedstock requires less amount of processing than coal and thus little transformative energy once it is at the power generation site. In addition, cofiring power plants generally have a higher degree of emission-offset rates. This is because they have higher efficiency in terms of feedstock heat recovery and require only a small amount of feedstock.

Liquid fuels, as compared to electricity, have relatively lower offset rates. Grain based ethanol has the lowest offset rate, while cellulosic ethanol and biodiesel from soybean oil have relatively higher offset values. The differential offset rates are due to the use of emission intensive inputs at varying rates when producing feedstocks (for example, growing corn requires a large amount of fertilizers) and emission intensive transformation processes in producing ethanol. Consequently, FASOMGHG also includes the standard byproducts and their markets; for example DDGS is produced as a byproduct from the ethanol dry grind process and can raise the corn GHG offset from 17% to 31%. However, the DDGS is blended with cattle feeds and cattle produce methane gas from enteric fermentation. Thus, FASOMGHG is able to account for these complex interactions. If GHG prices were to rise in the future, then there would be a shift in production away from grain based ethanol and toward cellulosic ethanol and electricity.

2.2 Leakage

Due to market forces and other factors, net GHG emission reductions within a region can be offset by increased emissions in other regions. For example, rising corn prices can help reduce net GHG emissions in the U.S., but stimulate increased emissions in other parts of the world due to expanded corn production. The net results are increased GHG emissions (Murray, McCarl and Lee, 2004; Searchinger et al.,2008). Many forms of this leakage phenomenon which are being discussed in many circles today include

- forests converted to crop land,
- reversion of Conservation Reserve Program (CRP) lands in the U.S. into crop land, and
- expansions of crop acres in Brazil and Argentina at the expense of grasslands and rainforest.

Leakage consideration suggests that bioenergy project GHG offsets need to be evaluated under broad national and international accounting schemes so that both the direct and indirect implications of project implementation are examined including offsite induced leakage. McCarl (2006) shows that international leakage can easily offset approximately 50% of the domestic diverted production, when GHG offsets per acre are equal and an even higher share of the net GHG gains if acres with higher emissions are involved. Searchinger et al. (2008) also show that net GHG emissions would increase when acres are directly replaced by rainforest reductions. FASOMGHG includes three types of leakages; it allows changes in land use, land taken out of CRP and changes in foreign production although the latter is not associated with carbon prices.

3 Bioenergy Production Possibilities

Producing bioenergy involves different feedstocks, opportunity costs, byproducts, and GHG emissions. Consequently, an overview of the production possibilities for ethanol, biodiesel, and biopower is provided in this section and how they are represented in FASOMGHG.

3.1 Ethanol

Gasoline has two potential substitutes: butanol and ethanol. Both can be produced from sugar/starch crops, agricultural residues, and wood byproducts via fermentation. Butanol, in general, has better fuel properties than ethanol; however, butanol can dissolve in water and can be toxic from long-term exposure (Product Safety Assessment n-Butanol 2006). Thus, this toxicity could prevent wide-scale adoption. Further, the EPA recently banned the use of MTBE as an oxygenate. The ban is fueling a strong demand for ethanol, because one gallon of ethanol offsets two gallons of MTBE (Reynolds 2000). Thus, this research focuses on ethanol as an additive to gasoline.

Biorefineries have three available technologies to produce ethanol. The first is the dry grind, and producers convert the sugar and starch feedstocks to ethanol. The feedstock is ground, steeped in water, then yeast ferments the sugars into ethanol, and the ethanol is separated from the mixture. Starch crops have one additional processing stage called hydrolysis, where the starch is converted to sugar. The ethanol yields are shown in Table 5. Many of the sugar and starch crops are exported or used in human food and animal feeds. Thus, a large ethanol industry could increase food prices because of the residual demand for feedstocks. The dry grind produces distiller's dried grain with solubles (DDGS) is blended with animal feeds. However, to transport DDGS, it has to be dried to less than 10% moisture content, increasing a biorefinery's energy costs.

FASOMGHG contains the sugar and starch fermentation shown in Table 5 along with DDGS. FASOMGHG does not contain wet distiller's grains (WDG) or modified distiller's grains (MDG). WGS is dried to a 65% moisture content and MDG is created by mixing WGS with grains until the mixture contains 50% moisture. Although, WGS and MDG require less energy to dry, WGS and MDG have a short shelf life, restricting their use to locations near the ethanol plant. Further, MDG and WGS would freeze in winter and spoil quickly in summer. Finally, the dry grind produces CO_2 as a byproduct. The food industry uses liquefied CO_2 to freeze, chill, and preserve food while the drink industry uses CO_2 to carbonate beverages. This CO_2 is included in the GHG emissions in FASOMGHG, because the CO_2 is eventually released into the atmosphere.

The second technology for ethanol is the corn wet mill and exclusively utilizes yellow dent corn as a feedstock. The wet mill separates corn kernels into a variety of products, making corn wet milling more capital intensive than the dry grind. However, they produce a variety of valuable products. The products are shown in Table 6. Two products, corn gluten meal and feed, are used in animal feeds. The other products arise from starch production and are the opportunity cost of ethanol production. A corn wet mill could sell starch directly to the markets or process the starch into corn syrup, dextrose, ethanol, or high fructose corn syrup. High fructose corn syrup is used as a sweetener by the beverage and confection industries. FASOMGHG contains markets for all products from the corn wet mill.

The third technology is lignocellulosic fermentation and is still in the experimental stage. Producers manufacture ethanol from crop and wood residues, and energy crops, like hybrid poplar, switchgrass, and willow. Lignocellulosic fermentation breaks down the cellulose and hemicellose from these feedstocks into five types of sugars. Thus, it requires more processing and is the most expensive process, but the feedstocks are the cheapest. The likely ethanol yields from lignocellulosic feedstocks are shown in Table 7 along with their energy content. FASOMGHG contains production possibilities for crop residues, energy crops like hybrid poplar, switchgrass, and willow, and wood residues.

FASOMGHG accounts for the CO_2 gas created from the fermentation and the byproduct of lignin. Lignin is a fiber that is extracted from the mixture before fermentation; it could be co-fired with coal to produce electricity. However, FASOMGHG does not include the byproducts of furfural and methane gas. Furfural could be used to make carpet fibers and methane gas could be collected and burned for heat and energy from the anaerobic fermentation of waste water.

FASOMGHG limits the amount of crop residues that can be harvested. Farmers leave some crop residues on the fields, because they reduce soil erosion and increase organic matter in the soil. Further, FASOMGHG allows ethanol to be produced from hard and soft wood residues. Thus, the ethanol industry competes with the lumber industry, because these wood residues could be processed into paper, particleboard, and mulches. Finally, FASOMGHG allows producers to switch land use. Producers could grow perennial energy crops like hybrid poplar, willow, and switchgrass, but they switch land use away from crops, pastures, or forests.

3.2 Biodiesel

Biodiesel is produced from vegetable oils and tallow. The main sources for the United States are soybean oil, corn oil, tallow, and yellow grease. All these oils can be blended with animal feeds and sold to cattle, poultry, and swine producers. Further, soybean oil and corn oil could be exported or used as human foods. A large biodiesel industry would thus cause higher food prices because of the demand for biodiesel feedstocks. Biodiesel production is quite efficient and is approximately a one-to-one gallon conversion of oil into biodiesel (Szulczyk and McCarl 2009). Additionally, biodiesel refineries could be small and may not require large amounts of capital. Thus, the vegetable oil and animal rendering plants can easily append a biodiesel production line.

FASOMGHG contains biodiesel production from four industries. First, soybean oil is produced from soybean crushing facilities. One pound of soybeans yields on average 0.19 pounds of oil and 0.41 pounds of soybean meal. Soybean meal is high in protein and is blended with animal feeds. Second, the corn wet mill supplies corn oil. Corn is the only feedstock in the United States that can be used to produce both ethanol and biodiesel.

Third, the beef cattle industry supplies both edible and nonedible tallow. From 100 lbs of meat one can obtain on average 5.4 pounds of edible tallow and about 11.0 pounds of non-edible tallow (Swisher 2004). Finally, biodiesel could be manufactured from waste cooking oil which comes in two types: yellow grease and brown grease. Yellow grease comprises less than 15% of free fatty acids, while brown grease exceeds this. The biodiesel industry would more than likely use yellow grease, because it involves less processing and cleaning. Yellow grease is one of the cheapest feedstocks for biodiesel, but requires higher processing and conversion costs. Approximately, one pound of oil produced from a corn wet mill or soybean crushing facility yields 0.13 pounds of yellow grease (Canakci 2007). This ratio is expected to increase over time as the biodiesel industry expands and the infrastructure improves for collecting, storing, and transporting yellow grease.

FASOMGHG does not contain glycerol production or a glycerol offset. Glycerol is a byproduct of the biodiesel industry and is used in pharmaceutical, cosmetic, and chemical industries. However, glycerol is a relatively small market and a large biodiesel industry could saturate the market, causing price to drop (Bender 1999; Ortiz-Canavate 1994). Therefore, the glycerol price may not be high enough to cover glycerol purification and higher capital costs.

3.3 Biopower

FASOMGHG allows both the lignocellulosic ethanol and bioenergy producers to compete for feedstocks from crop residues, wood residues, or energy crops. Electric power plants can cofire biomass with coal up to 100% biomass. However, a power plant has to invest in more capital to handle higher cofire rates. The energy contents of different feedstocks are shown in Table 7 and 32% of the heat energy can be converted to electricity (Spath, Mann, and Kerr 1999).

4 Economics of Biofeedstock

FASOMGHG contains two types of costs: endogenous and exogenous. The capital, production, and storage costs are exogenous, because bioenergy producers are assumed to be small relative to the market. Moreover, the feedstock and hauling costs are assumed to be endogenous and determined within FASOMGHG. The bioenergy producers compete with other industries for feedstocks. For example, higher feedstock demands lead to higher feedstock prices, thus producers switch to other feedstocks to reduce their costs. Further, transporting and hauling costs could comprise a significant portion of the costs because of the low bulk density of biomass. As the distance traveled increases between farmers and bioenergy producers, the hauling cost increases exponentially (see French 1960). FASOMGHG uses French's approximation for hauling costs. Hauling costs depend on the producers' production capacity, crop yields, and cost of hauling and harvesting the feedstocks, and technology. FASOMGHG incorporates the following technology parameters:

- Crop yields increase over time at rates forecasted by USDA (Interagency Agricultural Projections Committee 2008).
- Ethanol yields increasing over time where ethanol producers are assumed to attain 90% of theoretical chemical yield in 30 years, when total efficiency attains 90% of theoretical (Szulczyk, McCarl, and Cornforth 2009).
- The efficiency for lignin-electricity generation increases to 42% (Spath, Mann, and Kerr 1999), increasing 1.1% annually. The energy efficiency occurs as producers upgrade or build new electric generation facilities.

The biodiesel industry does not have any technological improvement, because biodiesel production is already quite efficient at 97% of theoretical (Szulczyk and McCarl 2009).

5 Predicted Bioenergy Production

For the analysis in this chapter, FASOMGHG is used to solve several scenarios such as varying fossil fuel and carbon prices and then predict future biofuel and biopower production levels. Thus, FASOMGHG allows researchers to predict the impact on the

U.S. agricultural markets as if the United States incorporated a cap and trade system for greenhouse gases. The energy prices are exogenous in FASOMGHG and are defined as:

- The gasoline and diesel fuel prices are wholesale prices expressed in dollars per gallon. The prices range from $1 to $4 per gallon, agreeing with the 25-year energy price forecasts from Office of Integrated Analysis and Forecasting (2006). Further, ethanol and biodiesel prices are adjusted for the lower energy content using the lower heating value.

- The coal price is expressed in dollars per ton and its base price is $24 per ton.

- The carbon equivalent price is expressed in dollars per equivalent metric ton. The agricultural industries emit or sequester carbon dioxide, methane, and nitrous oxide. These greenhouse gases are put in equivalent terms by using the 100-year global warming potential; carbon dioxide is defined as 1, methane as 21, and nitrous oxide as 310 (Adams et al. 2005; Cole et al. 1996).

The results are reported by bioenergy type.

5.1 The Case of Ethanol

Ethanol is used currently as a fuel additive and as a substitute for gasoline. Current gasoline engines with no engine modifications can operate up to 15% ethanol by volume for gasoline-ethanol blends while flexible fuel vehicles can use up to 85% ethanol by volume. Furthermore, 1.6 gallons of ethanol displaces one gallon of gasoline, because ethanol's life-cycle GHG emissions are adjusted to reflect ethanol's lower energy content. The predicted ethanol production level in millions of gallons of ethanol is shown in Figure 3 for various wholesale gasoline prices and Figure 4 for various carbon equivalent prices. Data are also shown in Table 8 and the gasoline price is fixed at $2 per gallon for the carbon equivalent prices. All time paths are identical for ethanol. Ethanol is restricted to its known production level for 2000 and 2005, which are 1.7 and 6.0 billion gallons of ethanol. Then new production capacity is constrained to grow at a maximum of 1.2 billion gallons per year, because only a handful of companies like Fagen International LCC, build ethanol facilities.

Alterations in the carbon equivalent price have a minor impact on the total size of the ethanol industry, as shown in Figure 4. However, under a carbon equivalent price there is a composition shift within the technologies used for ethanol production due to differences in their lifecycle emissions. A carbon equivalent price slightly contracts the ethanol production from the corn wet mills, but boosts production from lignocellulosic feedstocks with corn stover as the dominant feedstock. The results are shown in Figure 4 and data is in Table 8. This is because lignocellulosic fermentation is more GHG efficient than the other technologies. Crop residues also do not stimulate a great deal of leakage, because they provide a joint product.

5.2 The Case of Biodiesel

Biodiesel substitutes for #2 diesel fuel, and diesel engines with no modifications could use up to 100% of biodiesel by volume. Furthermore, we assume 1.05 gallons of biodiesel displaces one gallon of diesel fuel, adjusting the life-cycle GHG emissions for the different energy content between the two fuels. As shown in Figure 5 and in Table 8, the aggregate U.S. biodiesel production is in millions of gallons and a higher wholesale diesel fuel price boosts biodiesel production. For years 2000 and 2005, U.S. biodiesel production is constrained at its known values which are 5 and 250 million gallons respectively. The predicted biodiesel production is shown in Figure 6 for carbon equivalent prices; the diesel fuel price is fixed at $2 per gallon. Even though the GHG efficiency for biodiesel is extremely high, carbon equivalent prices have a small impact on biodiesel production. The reason is carbon equivalent prices boost the biopower. Moreover, biodiesel industry mainly relies on soybeans and corn as feedstocks, but also uses some tallow and yellow grease.

5.3 The Case of Biopower

Gasoline and diesel fuel prices have a minimal impact on the U.S. biopower production. As shown in Figure 7 and in Table 8, the aggregate U.S. biopower production is in 100 megawatts of electricity and the predicted biopower production greatly expands from higher carbon equivalent prices. However, when the carbon equivalent price is $0, biopower production drops to zero for all gasoline prices. Thus, the future market production of biofeedstocks for power generation may depend on the following factors: 1) the price of coal, 2) the price of GHG emissions, 3) the heat content of biofeedstocks, and 4) the costs of biofeedstock production. Maung and McCarl (2008) show that for crop residues to have economic potential in electricity generation, mostly in the form of cofiring, either the current price of coal or the price of GHG has to increase significantly.

This result not only applies to crop residues but also to switchgrass, willow, poplar and other feedstocks. The finding also indicates that generally feedstocks with higher heat content will have better potential in generating electricity than those with lower heat content. This implies that if farmers decide to invest in feedstocks, they should invest in feedstocks with relatively higher heat content such as bagasse. Moreover, results from our study suggest that if we are to induce electric power producers to consume feedstocks such as crop residues without any reliance on coal or GHG price increase, the production costs must be reduced by about 50 percent. But given the current market conditions of feedstocks, cost reductions of 50 percent will not be easy to achieve without drastic improvements in production technologies and integration of biofeedstock markets at the farm and industry levels.

Because coal is abundant in the U.S., its current and historical price have been relatively low and stable compared with the prices of natural gas and petroleum (see Figure 8). Without GHG price increases, electricity producers may be encouraged to choose coal for power generation as oil and gas prices increase.[1] The future competitiveness of biofeedstock and bio-based electricity would likely depend on how pricing GHG evolves over time and on the advancement in feedstock production and biopower generation technologies.

5.4 GHG Mitigation Strategy

The GHG mitigation role of agriculture changes as the prices of CO_2 and gasoline change. The national GHG summary (see Figure 9) as a function of the CO_2 and gasoline prices shows that under the scenario of low gasoline and low CO_2 prices, the predominant strategy involves agricultural soil sequestration. With low gasoline prices but higher CO_2 prices, the strategy is dominated by biofeedstock fired electricity because of its higher GHG offset rate. Higher gasoline prices may induce more liquid bioenergy production.

[1] This had happened in the past. During the energy crisis in the 70s, as oil and gas prices increased, electricity producers switched to coal. As a result, the demand for coal increased along with its price (Figure 4).

However GHG contributions of ethanol and biodiesel are limited because of their lower offset rates.

Figure 9 also shows that even at zero CO_2 price, a reduction in CO_2 emissions can take place only as a consequence of increased gasoline prices, which is a complementary policy. The figure suggests that if one were really after GHG mitigation, one would depend mainly on bio-based electricity. An important finding across all these scenarios involves the portfolio composition between agricultural soil sequestration and bioenergy. Specifically, when the prices of fossil fuel and CO_2 are low, agricultural soil sequestration is the predominant strategy as sequestration can be achieved more economically by changes in tillage practices that are largely complementary with existing production. But, if the CO_2 price gets higher, then a land use shift occurs from traditional production into bioenergy strategies. Consequently, the gains in carbon sequestration effectively discontinue, topping out the potential for agricultural soil carbon sequestration (McCarl and Schneider, 2001). This shift occurs because of higher fossil fuel or CO_2 prices, any of which induces a shift of land to biofeedstocks.

Another important finding involves the relative shares of cellulosic and grain based ethanol. When the gasoline price is high and CO_2 prices are low, grain based ethanol dominates the production but as the CO_2 price gets higher, the production shifts to cellulosic ethanol. This is largely due to the efficiency of GHG which induces the shift from grain based ethanol to cellulosic ethanol as the CO_2 price increases.

5.5 Food Prices

Biofuels have several criticisms. First, not only could a large biofuel industry divert feedstocks away from human food and animal feeds, but it also could increase prices on agricultural products from the stronger demand for feedstocks. Second, a carbon equivalent price can penalize cattle producers, because cattle emit methane gas from enteric fermentation.

FASOMGHG predicts corn prices in real terms in Figure 10 and in Table 8. The corn prices are in dollars per bushel. Higher carbon equivalent prices cause corn prices to be higher. However, corn prices peak in 2015 and begin to taper off. As already mentioned, ethanol producers begin to boost their production using agricultural residues and energy crops as feedstocks, lowering their demand for corn. Similarly, soybean prices are shown in Figure 11 and the price is in dollars per bushel. However, the rapid expansion of the biodiesel industry causes a large demand for soybeans, causing their price to increase over time. Further, higher carbon equivalent prices cause soybean prices to be higher. Finally, Figure 12 shows prices for slaughtered cattle in dollars per hundred pounds of meat. As expected, higher carbon equivalent prices cause higher meat prices, even though the biodiesel industry creates more soybean meal. Consequently, the higher agricultural prices from a GHG cap and trade system can put U.S. agricultural exports at a disadvantage.

6 Concluding Remarks

In this chapter, we address several major issues related to bioenergy and GHG offsets. Generally, GHG offset effects are different among different forms of bioenergy. Grain based ethanol has the lowest offset rates, while cellulosic ethanol and biodiesel have relatively higher offset rates, then followed by biopower which has the highest offset values. In the commodity markets, leakage created by induced replacement production overseas may offset the gains in domestic GHG emission reduction (Murray, McCarl and Lee, 2004).

Economically, GHG prices could play an important role in inducing the production and consumption of bioenergy. As GHG prices increase, the production would likely shift from grain based ethanol toward cellulosic ethanol, biodiesel and bioelectricity. Other factors which can influence the market penetration of bioenergy include prices of fossil fuels, heat content of biofuels, costs of production especially transport/hauling cost and improvements in production technologies.

Bioenergy may help the United States reduce petroleum imports, thus improving energy security. However, bioenergy feedstocks produced at large scale may have substantial opportunity costs, because they replace traditional food/feed crops or compete with them for limited agricultural lands. The feedstocks for biodiesel and corn-based ethanol compete with the cattle feed and human food supplies, thus potentially increasing food prices. However, lignocellulosic feedstocks are less competitive relying in part on crop residues plus on energy crops that have higher ethanol yields per acre than corn. Additionally, the impact on the U.S. trade deficit would be ambiguous, because a large ethanol and biodiesel industry could reduce the demand for petroleum imports, but at the same time the U.S. would be exporting less agricultural products either because of their reduced supply or their increased use by the ethanol industry.

Bioenergy and GHGs are complexly intertwined. In terms of policy implications, the arguments in this chapter suggest that current promotion of commodities like corn ethanol may not in fact be contributing much to GHG reductions particularly after considering leakage. Thus policies on GHG emission reduction need to be carefully designed to avoid leakage issues. Results in this chapter also suggest that the severity of leakage can be lessened with reliance on residue and waste products, with emphasis on cellulosic ethanol and bio-based electricity.

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Table 1. Percent of Net Electricity Generation by Different Fuel Sources, 1990 and 2005

Fuel Type\Year	***1990 (%)***	***2005 (%)***
Coal	52.65	50.04
Natural Gas	12.31	18.67
Nuclear	19.05	19.39
Petroleum	4.18	3.03
Hydro	9.67	6.59
Biomass	1.51	1.54
Geothermal	0.51	0.38
Solar	0.01	0.01
Wind	0.09	0.36

Source: Energy Information Administration

Table 2. Primary Crops and Livestock in FASOMGHG

Category	Activity
Primary Crops	Barley, citrus, corn, cotton, hay, oats, potatoes, rice, silage, sorghum, soybeans, sugar beets, sugarcane, tomatoes, and wheat
Energy Crops	Hydrid poplar, switchgrass, and willow
Livestock	Beef cattle, dairy cattle, hogs, horses and mules, poultry, and sheep
Misc.	Eggs

Source: Adams et al. (2005)

Table 3. Major Secondary Products in FASOMGHG

Category	Activity
Animal products	Beef, chicken, edible tallow, non-edible tallow, pork, turkey, and wool
Bio-energy	Biodiesel, ethanol, and electricity
Corn wet mill	Corn oil, corn starch, corn syrup, dextrose, high fructose corn syrup, and gluten feed
Dairy products	American cheese, butter, cream, cottage cheese, ice cream, and milk
Potato products	Dried potatoes, frozen potatoes, and potato chips
Processed citrus products	Grapefruit and orange juice
Refined sugar items	Refined cane sugar and refined sugar
Soybeans	Soybean meal and soybean oil
Sweetened products	Baking, beverages, confection, and canning

Source: Adams et al. (2005)

Table 4. Percentage offset of net GHG emissions from the usage of a biofeedstock

	Form of Bioenergy being Produced				
	Liquid Fuels			**Electricity**	
Feedstock Commodity being used	**Crop Ethanol**	**Cellulosic Ethanol**	**Biodiesel**	**Cofire at 5 %**	**Fire with 100% biomass**
Corn	30.5				
Hard Red Win. Wht.	31.5				
Sorghum	38.5				
Softwood Residue		80.0		99.2	97.4
Hardwood Residue		79.9		99.0	96.5
Corn Residue		75.1		93.7	88.1
Wheat Residue		73.8		95.6	91.4
Cattle Manure				99.6	96.5
Switch Grass		68.6		94.3	89.5
Hybrid Poplar		61.9		94.1	89.1
Willow		67.7		96.6	93.7
Soybean Oil			70.9		
Sugarcane	64.8				
Corn Oil			55.0		
Sugarcane Bagasse		90.1		100.0	100.0
Lignin				91%	86%

Table 5. Ethanol and DDGS Yields from Sugar and Starch Crops

Feedstock	Sugar Content (%)	Starch Content (%)	Ethanol Chemical Yield (gal/ton dry feed stock)	DDGS (lbs/ethanol gallon)
Barley	–	50-55	67.6 – 74.8	
Corn (dry grind)	–	72	96.1 – 96.7	5.9-6.4
Grain sorghum	–	67-73.8	82.7 – 106.1	7.9
Oats	–	64.0	86.5 – 87.0	9.9
Potato	–	15.0	20.3 – 20.4	6.7
Rice grain	–	74.5	100.7 – 101.2	5.3
Sugar beet	16 – 17.3	–	20.0 – 21.8	14.2
Sugarcane		–	15.9 – 16.7	14.9
Sweet Sorghum	13.0	–	16.1 – 16.2	7.9
Sweet potato	–	26.7	36.1 – 36.3	6.7
Wheat	–	57.9	87.0 – 87.4	7.3 – 9.2

Source: Szulczyk, McCarl, and Cornforth (2009)

Table 6. Corn Wet Mill Possibilities

Input	Output
1 bushel corn	31.5 lbs of starch or 2.8 gallons of ethanol and 1.5 lbs of corn oil and 2.6 lbs of corn gluten meal and 13.5 lbs of corn gluten feed
1 pound of starch	1.3 lbs of corn syrup or 1.19 lbs of dextrose or 1.41 – 1.54 lbs high fructose corn syrup (HFCS)

Sources: National Corn Growers Association 2007; Rausch and Belyea 2006; Light 2007

Note: HFCS comes in two types. The sweeter HFCS is used in carbonated drinks while the less sweet HFCS is used in everything else.

Table 7. Lignocellulosic Ethanol Yields and Energy Content

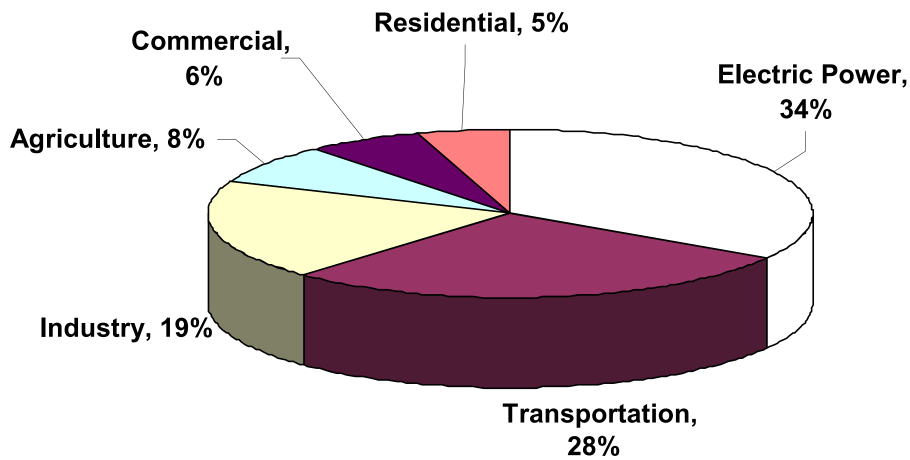
Feedstock	Ethanol Yield Gal./ton of feedstock	Energy Content BTU/ton of feedstock
Crop residues		
Bagasse	49.8 – 90.7	16,376,000
Barley straw	60.00 – 74.4	14,894,000
Corn Stover	51.25 – 92.78	15,186,000
Oat straw	60.00 – 62.4	NA
Rice Straw	45.67 – 83.81	14,008,000
Sorghum straw	39.70 – 71.79	NA
Wheat Straw	49.47 – 89.54	15,066,000
Lignin	–	18,222,000
Wood residues		
Softwoods	55.96 – 87.33	NA
Hardwoods	48.03 – 84.71	16,092,000
Energy crops		
Hybrid popular	46.90 – 82.39	15,444,000
Switchgrass	43.67 – 78.78	NA
Willow	NA	14,336,000
Miscellaneous		
Manure	–	15,408,000

Sources: Domalski, Jobe, and Milne (1986); Szulczyk, McCarl, and Cornforth (2009)

Table 8. Results from FASOMGHG

	2000	2005	2010	2015	2020	2025	2030
Ethanol (millions of gallons)							
Gas Price $1, CO2 Price $0	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $2, CO2 Price $0	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $3, CO2 Price $0	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $4, CO2 Price $0	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Ethanol (millions of gallons)							
Gas Price $2, CO2 Price $0	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $2 CO2 Price $10	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $2 CO2 Price $25	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $2 CO2 Price $50	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Gas Price $2 CO2 Price $100	1,701.7	6,006.0	12,012.0	18,018.0	24,024.0	30,030.0	36,036.0
Ethanol (millions of gallons)							
Corn Wet Mill, CO2 Price $0	1,531.5	4,359.9	9,825.0	12,101.9	12,101.9	12,101.9	12,101.9
Lignocellulosic, CO2 Price $0	0.0	0.0	0.0	2,802.8	10,095.7	16,147.0	22,325.6
Corn Wet Mill, CO2 Price $100	1,531.5	4,875.2	9,788.6	9,788.6	9,788.6	9,788.6	9,788.6
Lignocellulosic, CO2 Price $100	0.0	0.0	174.5	2,977.3	13,626.2	19,329.8	24,794.7
Biodiesel (millions of gallons)							
Gas Price $1, CO2 Price $0	5.3	250.1	2,739.9	2,126.5	2,550.1	2,592.7	2,693.4
Gas Price $2, CO2 Price $0	5.3	250.1	3,102.7	3,100.6	3,222.2	3,265.6	3,312.8
Gas Price $3, CO2 Price $0	5.3	250.1	3,610.7	3,716.1	3,816.4	3,863.1	3,912.7
Gas Price $4, CO2 Price $0	5.3	250.1	3,765.6	3,985.3	4,019.6	4,126.9	4,429.5
Biodiesel (millions of gallons)							
Gas Price $2, CO2 Price $0	5.3	250.1	3,102.7	3,100.6	3,222.2	3,265.6	3,312.8
Gas Price $2 CO2 Price $10	5.3	250.1	3,146.6	3,135.4	3,245.8	3,291.8	3,573.9
Gas Price $2 CO2 Price $25	5.3	250.1	3,183.3	3,158.7	3,232.8	3,367.8	3,549.4
Gas Price $2 CO2 Price $50	5.3	250.1	3,225.5	3,048.1	3,207.7	3,406.2	3,394.7
Gas Price $2 CO2 Price $100	5.3	250.1	3,254.9	3,153.3	3,398.3	3,470.0	3,083.6
Biopower (100 MW)							
Gas Price $2, CO2 Price $0	11.9	12.2	15.5	0.0	0.0	0.0	0.0
Gas Price $2 CO2 Price $10	14.9	16.3	18.6	5.8	21.1	28.9	38.8
Gas Price $2 CO2 Price $25	30.1	28.7	40.2	36.8	54.9	83.4	89.0
Gas Price $2 CO2 Price $50	36.0	38.0	52.7	49.8	69.4	87.5	107.3
Gas Price $2 CO2 Price $100	113.7	119.8	171.9	221.2	259.8	312.4	334.3
Corn Price ($ per bushel)							
Gas Price $2, CO2 Price $0	2.55	3.27	3.44	3.42	3.22	3.05	2.93
Gas Price $2 CO2 Price $10	2.59	3.30	3.42	3.45	3.21	3.04	2.98
Gas Price $2 CO2 Price $25	2.67	3.39	3.42	3.52	3.26	3.05	3.08
Gas Price $2 CO2 Price $50	2.78	3.47	3.51	3.55	3.34	3.11	3.19
Gas Price $2 CO2 Price $100	3.07	3.80	3.89	3.87	3.60	3.37	3.43
Soybean Price ($ per bushel)							
Gas Price $2, CO2 Price $0	6.33	11.41	11.69	11.31	11.65	11.70	11.90

Gas Price $2 CO2 Price $10	6.43	11.50	11.79	11.40	11.75	11.79	11.98
Gas Price $2 CO2 Price $25	6.57	11.65	11.93	11.55	11.66	11.92	11.97
Gas Price $2 CO2 Price $50	6.89	11.89	12.02	11.79	11.91	11.96	12.16
Gas Price $2 CO2 Price $100	7.73	12.35	12.28	12.28	12.39	12.44	12.87
Beef Slaughtered Price ($ per CWT)							
Gas Price $2, CO2 Price $0	81.71	78.54	80.41	80.87	85.09	87.57	92.14
Gas Price $2 CO2 Price $10	82.89	79.82	81.58	81.53	86.34	88.93	93.07
Gas Price $2 CO2 Price $25	85.29	81.71	83.75	81.60	88.25	90.34	96.08
Gas Price $2 CO2 Price $50	89.13	86.46	86.55	84.05	91.82	95.17	103.01
Gas Price $2 CO2 Price $100	100.44	94.95	94.94	95.17	99.91	103.21	107.64



Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA)

Figure 1. U.S. CO2 Emissions by Sector in 2005

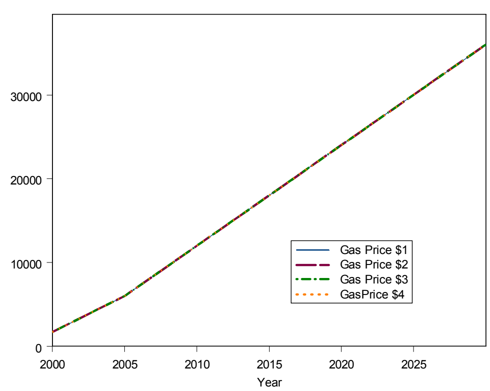


Figure 2. Predicted Aggregate U.S. Ethanol Production (million gallons)

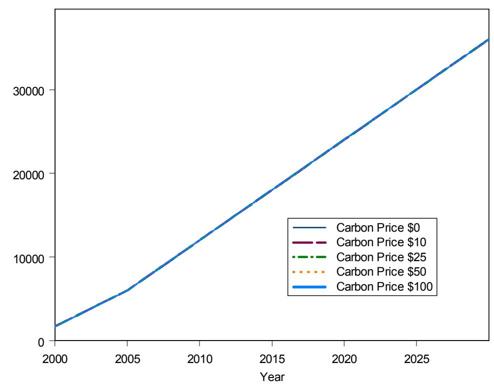


Figure 3. Predicted Aggregate U.S. Ethanol Production (million gallons)

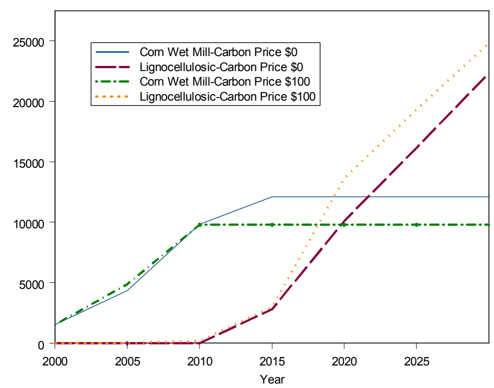


Figure 4. Predicted U.S. Ethanol Production – Corn Wet Mill versus Lignocellulosic (million gallons)

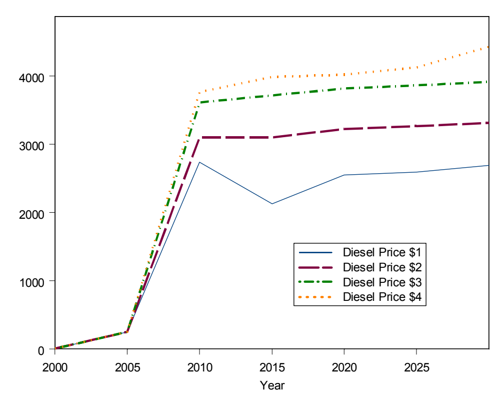


Figure 5. Predicted Aggregate U.S. Biodiesel Production (million gallons)

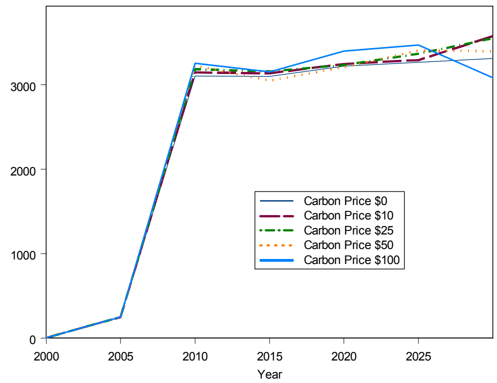


Figure 6. Predicted Aggregate U.S. Biodiesel Production (million gallons)

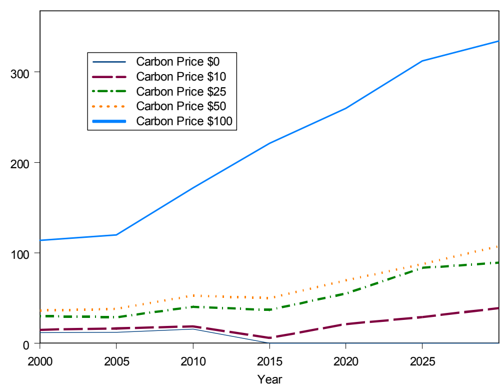
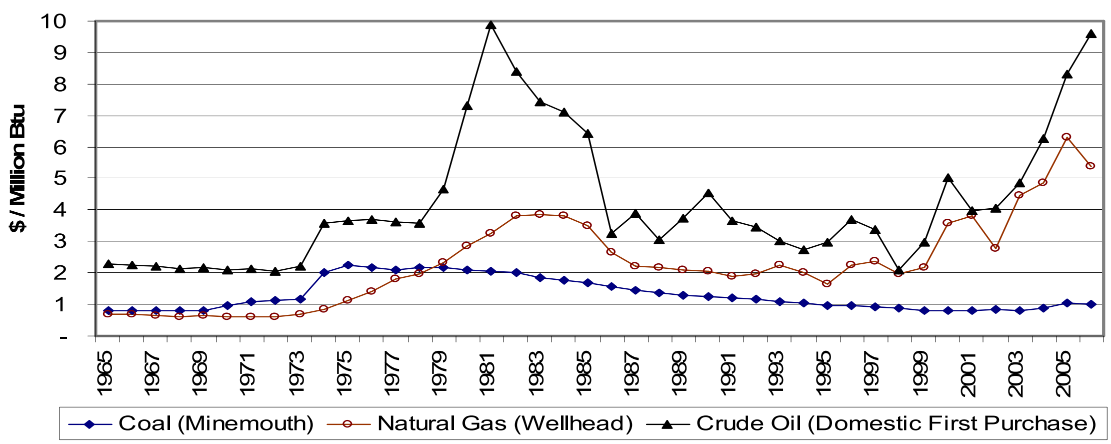
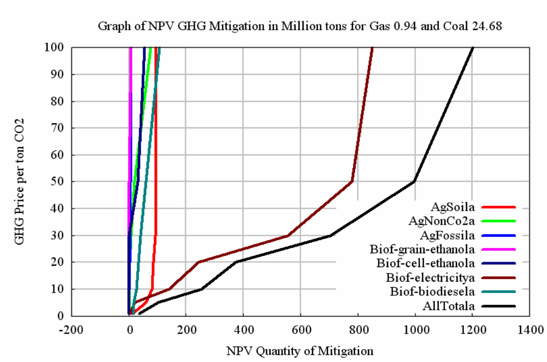


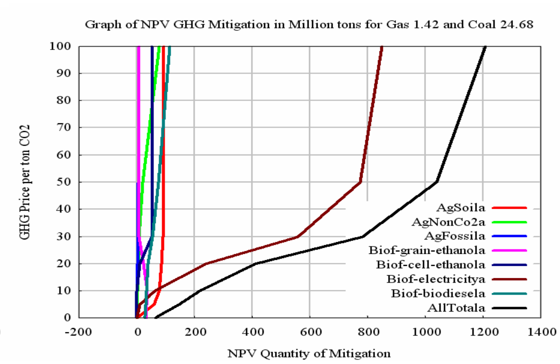
Figure 7. Predicted Aggregate U.S. Biopower (100 MW)



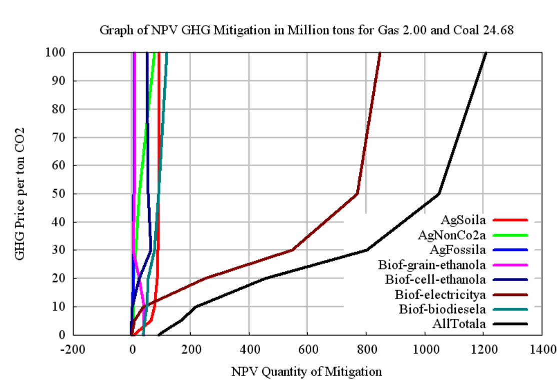
Source: Energy Information Administration

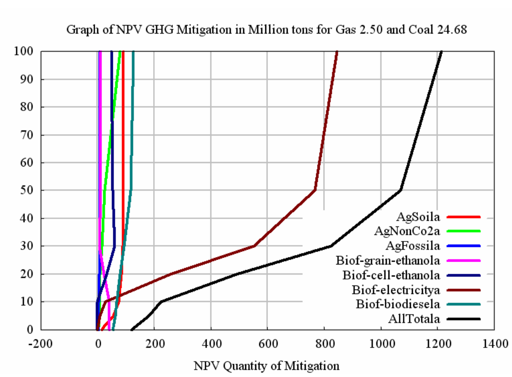
Figure 8. Average Annual Real Fossil Fuel Prices, 1965 to 2006





Panel (a) Gas Price $0.94 / Gallon (b) Gas Price $1.42 / Gallon





Panel (c) Gas Price $2.00 / Gallon (d) Gas Price $2.50 / Gallon

Figure 9. GHG Mitigation Strategy Use for Alternative Gasoline and GHG/Carbon Dioxide Prices

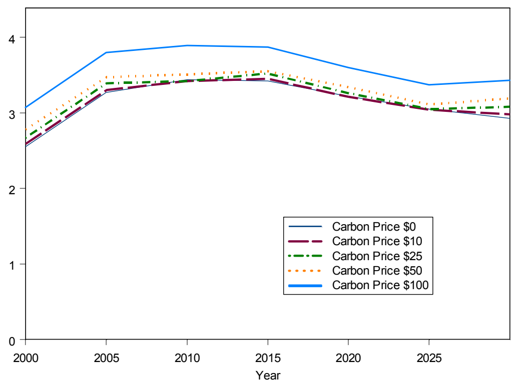


Figure 10. Predicted U.S. Corn Prices ($ per bushel)

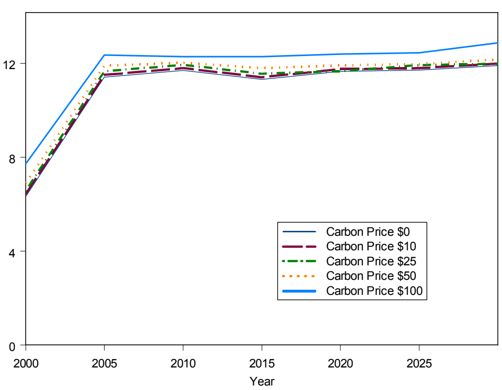


Figure 11. Predicted U.S. Soybean Prices ($ per bushel)

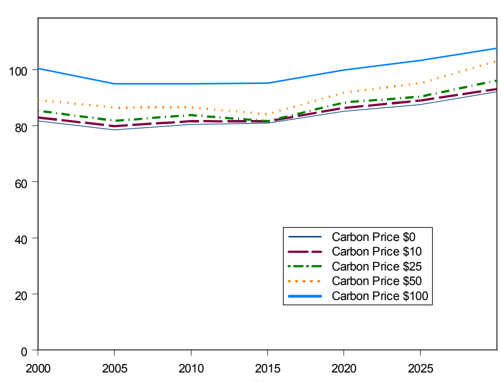


Figure 12. Predicted Slaughtered Cattle Prices ($ per 100 pounds)